Sodium bicarbonate ingestion and individual variability in time to peak pH

S. Andy Sparks[1], Emily Williams[1], Amy Robinson[1], Peter Miller[1], David Bentley[2], Craig Bridge[1] and Lars R. Mc Naughton[1]

1 Edge Hill University Exercise Nutrition Research Group, Department of Sport and Physical Activity, Edge Hill University, Ormskirk UK

2 Flinders University, Adelaide, South Australia, Australia

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Corresponding author:

Professor Lars Mc Naughton

Edge Hill University

Department of Sport and Physical Activity

St Helen’s Road

Ormskirk L39 4QP

United Kingdom

Phone: +44 1704541967

Email: lars.mcnaughton@edgehill.ac.uk

Abstract

The aim of this study was to determine the individual variability in time to peak pH after the consumption of a $300 mg \cdot kg^{-1}$ dose of sodium bicarbonate ($NaHCO_3$). Seventeen active males volunteered to participate in the study (mean ± SD: age 21.38 ± 1.5y; mass 75.8 ± 5.8kg; height 176.8 ± 7.6cm). Participants reported to the laboratory where a resting capillary blood sample was taken aseptically from the fingertip. After this, 300 $mg \cdot kg^{-1}$ of $NaHCO_3$ in 400ml of water with 50ml of flavoured cordial was ingested. Participants then rested for 90 min during which repeated blood samples were procured at 10 minute intervals for 60 mins and then every 5 min until 90 min. Blood pH concentrations were measured using a blood gas analyser. Results suggested that time to peak pH (64.41±18.78 min) was highly variable with a range of 10-85 min and a coefficient of variation of 29.16%. A bi-modal distribution occurred, at 65 and 75 min. In conclusion, researchers and athletes, when using $NaHCO_3$ as an ergogenic aid, should determine, in advance their time to peak pH to best utilise the added buffering capacity this substance allows.

Key Words: Performance, individual response, buffering, acidity

Introduction

Sodium bicarbonate ingestion is used a popular method of improving buffering against hydrogen ions induced by high intensity short duration exercise. There have been a number of review articles which have reaffirmed its effectiveness as an ergogenic aid when consumed prior to exercise performance lasting up to 10 minutes in duration [1, 2, 3]. A relatively recent meta-analysis of the effects of sodium bicarbonate ingestion on high intensity exercise performance suggested that the most effective pre-exercise doses should be between 0.3-0.5g/kg/BM, which is likely to improve mean power by 1.7±2.0% [4] in appropriate exercise. Indeed it is this type of exercise that elicits the intracellular accumulation of hydrogen ions (H^+), which have been implicated as a cause of muscular fatigue[5], typically occurring as a by-product of anaerobic glycolysis. This energy system is predominantly used in high intensity exercise, including repeated sprint activity (RSA), usually lasting less than a total of 10 minutes.

Although some evidence suggests that, at physiological temperatures, direct inhibition of force production by acidification is not as great as previously thought[6], interventions that minimize intracellular H^+ accumulation may improve RSA. H^+ accumulation depends on both the production and removal of H^+. The intra- and extracellular buffer systems act to reduce the build-up of free H^+ during high-intensity exercise and may therefore be important in maintaining repeated-sprint performance. Indeed, Bishop et al.[7] have reported a significant relationship between RSA and both change in blood pH and *in vivo* muscle buffer capacity[8]. The intracellular accumulation of H^+ also depends on the extracellular H^+ concentration. H^+ efflux out of the muscle cell has been reported to be inhibited by extracellular acidosis[9] and enhanced by a greater extracellular buffer concentration[10]. It is therefore frequently hypothesized that increases in the extracellular buffer concentration, via the ingestion of an alkaline solution such as sodium bicarbonate

($NaHCO_3$), may improve H^+ efflux out of the muscle cell and improve repeated-sprint performance[11].

It is now however generally accepted that the increased H^+ production causes competition on the ionisable binding sites of the actin / myosin complex, as well as sarcoplasmic reticulum dysfunction with regard to Ca^{2+} release and uptake[12, 13, 14]. With respect to both of these models of skeletal muscle fatigue, attenuating the increase in muscle (and subsequently blood) acidosis should help delay the onset of fatigue during repeated bouts of high intensity exercise, thereby helping to minimise the decline in power output inevitable during this type of exercise. Although not conclusive, it appears that increasing the blood buffering potential via $NaHCO_3$ ingestion either creates an electro-chemical gradient between the intra- and extracellular milieu, thus allowing for greater facilitation of proton removal from inside the cell; or sustains Ca^{2+} release and re-sequestering in the sarcoplasmic reticulum by increasing the strong ion difference[15]. Sustaining these mechanisms may prolong skeletal muscle function and perhaps maintain exercise performance, but the degree of efficacy in enhancing physical performance remains equivocal[1].

As a result of the mechanisms by which this supplement may act to delay fatigue, many laboratory investigations have used a variety of relevant exercise models including running[16, 17, 18], cycling [11, 19, 20,21], boxing and swimming [22, 23] in order to assess its effectiveness. Indeed, such is the wealth of published studies on sodium bicarbonate, that recently, researchers have started to focus on its co-ingestion with other active ingredients such as caffeine [24, 25] and β-alanine [26, 27, 28] in order to assess the potential additive effects in order to provide further performance enhancements via the activation of different ergogenic mechanisms simultaneously.

Christensen et al.[29] performed a study using elite rowers, which is one of the few investigations that have not demonstrated an ergogenic effect of sodium bicarbonate. Their protocol required participants to complete a 6 min time trial task following a dose of 3 $g.kg^{-1}$ ingested 75 min prior to the start of the performance test. An additional condition of the study also used this same dose of sodium bicarbonate co-ingested with a 3 $mg.kg^{-1}$ dose of caffeine. In the caffeine trials they observed a significant improvement in performance which was not observed in either the co-ingestion trial or with a single dose of sodium bicarbonate. Interestingly, there is some variety in the timing of pre-exercise administration in the literature which typically ranges from 60-90 min [29, 30, 31, 32]. In some cases a multiple acute dose has been used starting at 90 mins and continuing until 50 min pre-exercise [33] or more chronic supplementation across several days [34]. This range of pre-exercise ingestion times are likely to influence the effectiveness of the supplement and therefore the magnitude of the potential performance benefits which are reported. Presently there is no standardised pre-exercise ingestion time which has been determined as most effective, and there are also some suggestions that training status, diet and activity may affect buffering capacity. We hypothesize that these factors lead to considerable inter-individual variation in the time at which optimal buffering may occur following the ingestion of supplements designed to alter the pH of the blood. Therefore the aim of this experiment was to determine the variability in individual responses to a single bolus of sodium bicarbonate.

Methods

Participants

Seventeen male active team and individual sports participants (mean ± SD: age 21.38 ± 1.5y; mass 75.8 ± 5.8kg; height 176.8 ± 7.6cm) volunteered to take part in the study. All participants were familiar with high-intensity exercise and on took part in a minimum of two hours of intermittent team or individual sporting activity per week. All participants were informed of both the benefits and the potential side effects associated with the study (both verbally and in writing), before they provided written informed consent and then underwent screening. The study was approved by the institutional Departmental Ethics Committee. Following screening

Procedures

The participants attended the laboratory once in order to obtain basic anthropometric measurements and to determine each individuals resting blood pH responsiveness to $NaHCO_3$ ingestion. Following the screening and anthropometric data collection participants ingested 300 $mg{\cdot}kg^{-1}$ (BM) of $NaHCO_3$ taken in 400 ml of water with 50 ml of flavoured cordial (Robinsons Fruit Squash, UK). This method has previously been used by Price et al. [35] as it has been shown to improve drink palatability [36]. Participants were asked to refrain from maximal exercise, to maintain a typical diet and avoid consuming alcohol and beverages other than water for the 24 hour period prior to their laboratory trial in order to minimise disturbances to normal acid-base status [36, 37, 38].

At the visit, participants reported to the laboratory where a 300 µl resting capillary blood sample was taken aseptically from the fingertip. The participants then consumed 300 $mg{\cdot}kg^{-1}$ of $NaHCO_3$ in 400ml of water with 50ml of flavoured cordial within a five minute period. This dose has previously been found to improve individual anaerobic performance [19, 39, 40] as well as repeated sprint performance [41] in men and women [19, 21, 39]. Participants then rested quietly for a 90 min period following the completion of ingestion. During this time additional capillary blood samples were procured at 10 minute intervals for the first 60 min and then at 5 min intervals until 90 min. Blood pH concentrations were measured using a blood gas analyser (Radiometer ABL800, Denmark).

Statistical Analysis

All data were assessed for normality using standard graphical methods prior to analysis [42]. Blood pH responses over the post ingestion period were assessed using repeated measures ANOVA. Post hoc pair-wise comparisons were made using a Bonferroni adjustment and statistical significance was assumed as $p < 0.05$. Calculations of effect sizes were done using partial eta squared (ηp^2) for ANOVA. The conventional interpretations of Cohen [43] were used to evaluate effect sizes where < 0.20 = trivial, 0.20-0.49 = small, 0.50-0.79 = moderate, and large ≥ 0.80 = large. All data are presented as mean ± SD and were analysed using SPSS v22 for Windows (SPSS Inc., Chicago, IL, USA).

Results

The ingestion of the sodium bicarbonate bolus had a significant effect on pH ($f = 16.08$, $p < 0.001$, $\eta p^2 = 0.50$). Indeed the post ingestion pH values were all significantly higher than the pre-ingestion sample ($p < 0.05$). Most notably there was a significant increase in pH at the 10 ($p = 0.007$) and 20 min ($p < 0.001$) sample points compared to the pre ingestion values (Figure 1A). There was a further increase in pH after 40 min compared to the 20 min value ($p = 0.01$) after which pH did not significantly change until a decrease occurred between 75-80 min ($p = 0.03$). There were further significant decreases in pH between 75-85 min ($p = 0.006$) and 75-90 min ($p = 0.018$). Mean time to peak pH was 64.41±18.78 min with a coefficient of variation of 29.16%. Furthermore between subject effects analysis revealed that there was significant variation in the pH responses ($f = 5830237.7$, $p < 0.001$, $\eta p^2 = 1.00$). The times to peak pH to determine the optimum loading period strategy, are shown in Table 1 with the range of times spread between

10-85 min (Figure 1B). Time to peak pH frequency was bi-modally distributed between 65 and 75 min.

The correlation between time to peak pH and time to bicarbonate peak time was r=0.95, (p=0.001). Peak pH achieved was not correlated to weight, with a low correlation (r=0.07, p=0.79) and neither was weight correlated to change in minimum-maximum pH achieved, r=0.124, p=0.64).

Discussion and Conclusion

The results of this study suggest that after ingestion of a bolus of $300 mg \cdot kg^{-1}$ body mass of sodium bicarbonate, the time to reach peak pH is variable, with a range of 10-85 min. This suggests that when used as an ergogenic aid to improve sprint performance, in studies that have either used 60 min after ingestion [23, 35] or 90 min post ingestion [20, 21, 44], the time lag is probably too short (60 min) or too long respectively. This is supported by the fact that the mean time to peak pH, across all participants is 65.0±18.4 min, confirming that an exercise time of 60-90 min post ingestion is either too short, or too long respectively. Hence, this would then suggest that these participants are not making the most of the possible ergogenic, buffering capacity allowed by the ingestion of $NaHCO_3$.

It is not possible to predict pH on the basis of a participant's body mass as the correlation between body mass and peak pH was low. Neither is it possible to predict maximum pH values on the basis of body weight. As has been seen previously [20, 21, 44], responses to the same dose of are varied with respect to changes in pH even when resting pH values are almost identical.

In conclusion, researchers, athletes and coaches should endeavour to undertake testing to ensure that if sodium bicarbonate is being used as an ergogenic aid, that their time to peak pH is known so that performance can be maximised at the time when peak pH is achieved. This will require analysis with blood gas analysers which can be found in hospitals and at some academic institutions.

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Table 1. Individual responses to ingestion of 300mg·kg^{-1} sodium bicarbonate

	Time (mins)												
Participant	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**65**	**70**	**75**	**80**	**85**	**90**
1	7.409	7.433	7.441	7.465	7.485	7.49	7.495	7.495	7.489	7.496	7.499	**7.528**	7.520
2	7.410	7.431	7.453	7.476	7.485	7.473	7.467	7.483	7.506	**7.517**	7.512	7.508	7.498
3	7.390	7.429	7.452	7.459	7.475	7.475	7.497	7.485	7.491	**7.518**	7.482	7.513	7.489
4	7.429	7.472	7.462	7.443	7.472	7.447	7.495	**7.517**	7.509	7.501	7.499	7.478	7.476
5	7.431	7.45	7.457	7.477	7.468	7.47	7.472	**7.484**	7.484	7.468	7.465	7.463	7.448
6	7.388	7.416	7.448	7.429	7.466	7.468	7.457	7.460	7.465	7.477	**7.484**	7.450	7.450
7	7.414	**7.482**	7.480	7.474	7.473	7.468	7.461	7.459	7.454	7.451	7.447	7.445	7.442
8	7.411	7.454	7.457	7.460	7.481	7.477	7.494	**7.518**	7.494	7.513	7.495	7.503	7.498
9	7.439	7.459	7.471	**7.486**	7.468	7.456	7.476	7.465	7.472	7.471	7.457	7.465	7.469
10	7.454	7.474	7.494	7.488	7.508	7.48	7.500	**7.501**	7.496	7.483	7.486	7.473	7.472
11	7.42	7.434	7.454	7.428	7.439	7.469	7.453	7.451	**7.471**	7.449	7.455	7.44	7.471
12	7.468	7.452	7.516	7.521	7.507	**7.516**	7.510	7.459	7.462	7.466	7.443	7.445	7.44
13	7.417	7.423	7.441	7.445	7.45	7.44	7.457	**7.465**	7.462	7.463	7.451	7.446	7.441
14	7.447	7.407	7.448	7.482	7.457	7.486	7.48	7.477	**7.486**	7.465	7.485	7.461	7.49
15	7.403	7.406	7.456	7.438	7.46	7.464	7.444	7.462	7.481	**7.487**	7.448	7.452	7.441
16	7.431	7.444	7.461	7.447	7.46	7.488	7.477	7.497	7.487	**7.509**	7.474	7.49	7.487
17	7.419	7.426	7.431	7.446	7.454	7.467	7.464	7.483	7.477	**7.49**	7.48	7.481	7.477
Mean	**7.422**	**7.441**	**7.460**	**7.463**	**7.471**	**7.473**	**7.476**	**7.480**	**7.482**	**7.484**	**7.474**	**7.473**	**7.471**
SD	**0.021**	**0.023**	**0.021**	**0.025**	**0.018**	**0.017**	**0.019**	**0.021**	**0.016**	**0.023**	**0.021**	**0.027**	**0.024**

Note: Peak pH is illustrated in bold font.

Figure 1. Mean (±SD) changes in pH following sodium bicarbonate ingestion (A) and individual participant time to peak pH frequency (B). (*) Denotes a significant increase in pH from the previous time point ($p < 0.01$). (•) Denotes a significant increase in pH from the 20 min sample $p \leq 0.01$. (∆) Denotes a significant decrease in pH from the 75 min sample ($p < 0.05$).